Tests of PSF models

DARK ENERGY SURVEY

Weak Lensing Tests for DES SV Data

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This document will remain active until the work has moved into paper repositories.

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Tests of PSF models

5.1.2 Tests of PSF on simulations

Andres Plazas

The shapelet PSF code has been well tested on simulations. It gives suitably unbiased estimates of known input PSF profiles down to S/N ~ 40.

The PSFEx models have not been well tested by the WL group. (Presumably Emmanuel did some kind of testing, but we don't know how involved that was.)

Andres is starting to look at some tests similar to the above shapelet tests to see how well it recovers known inputs.

PSFEx

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* Code by E. Bertin (Source Extractor, SCAMP, SWARP, etc. - TERAPIX)

- The PSF is tabulated at a resolution which depends on the stellar FWHM (typically 3 pixels/FWHM)
  - Satisfy the Nyquist criterion + margin for Lanczos interpolation
  - Handle undersampled data by representing the PSF model on a finer grid
  - Minimize redundancy in cases of bad seeing
  - Find the sample values by solving a system using point-sources located at different positions with respect to the pixel grid

- The PSF is modelled as a linear combination of basis functions ψ_b
  - "Natural" pixel basis $\psi_b(\mathbf{x}) = \delta(\mathbf{x}-\mathbf{x}_b)$
    - Work with any diffraction-limited image (images are bandwidth-limited by the autocorrelation of the pupil)
  - Gauss-Hermite or Gauss-Laguerre basis functions (aka *Shapelets*)
    - Scale parameter (β) adjusted to provide proper sampling
    - Provide a more robust model for data with low S/N
  - One might use PCA components of the theoretical PSF aberrations for diffraction-limited instruments.

Credit: E. Bertin

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"measurepsf" (shapelets)

- Code by Mike Jarvis (Penn) and Erin Sheldon (BNL), implementing method in Bernstein and Jarvis 2002.

$$I(r,\theta) = \sum_{p,q\geq 0} b_{pq}\psi^{\sigma}_{pq}(r,\theta)$$

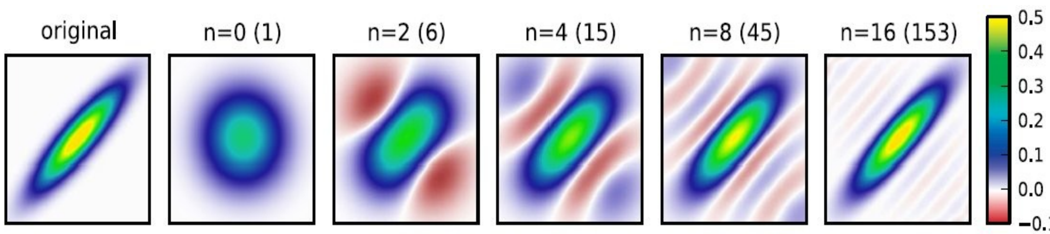
- Measures a Gauss-Laguerre (shapelets) expansion for the stars of an image and then calculates an interpolating function (e.g., Legendre Polynomial) for the PSF expansion at any location of the image.

$$\psi^{\sigma}_{pq}(r,\theta) = \frac{(-1)^q}{\sqrt{\pi}\sigma^2}\sqrt{\frac{q!}{p!}}\left(\frac{r}{\sigma}\right)^m e^{im\theta}e^{-r^2/2\sigma^2}L^{(m)}_q\left(\frac{r^2}{\sigma^2}\right)$$

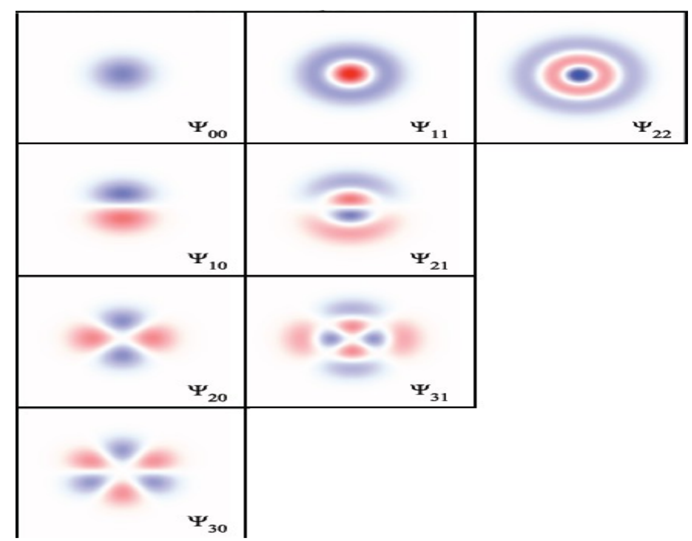
$$(p \geq q)$$

$$m \equiv p - q$$

* Shapelets can be summed together to model galaxy and PSF morphologies:



Credit: Bosh 2010



Credit: Bernstein and Jarvis 2002

Old tests with measurepsf

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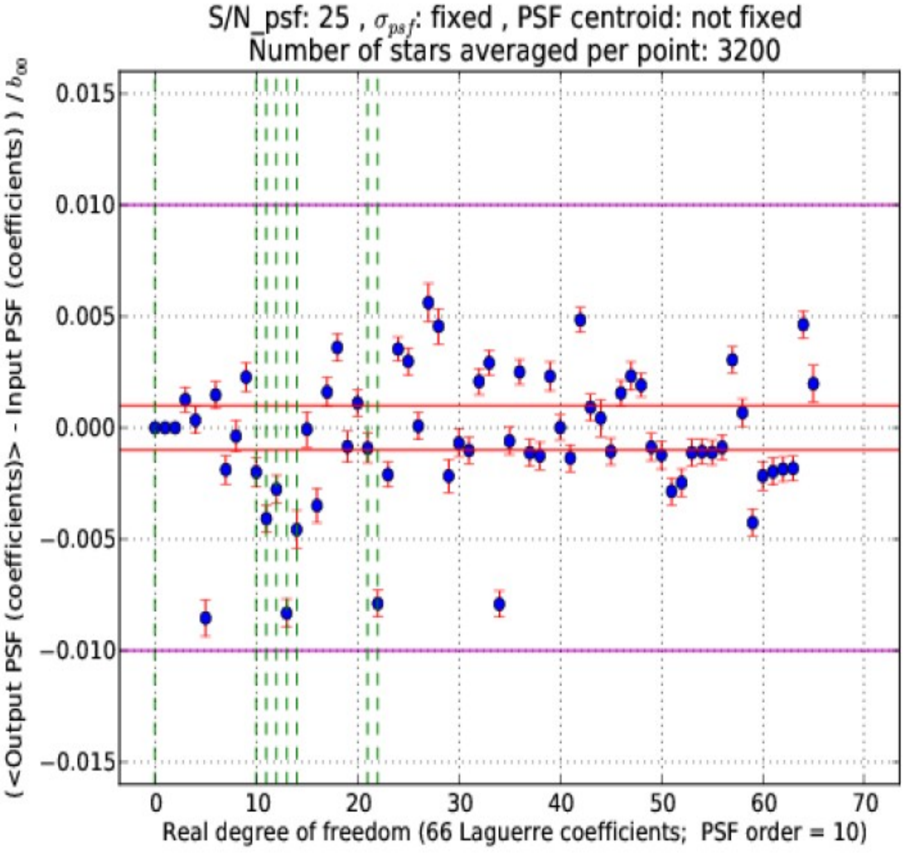
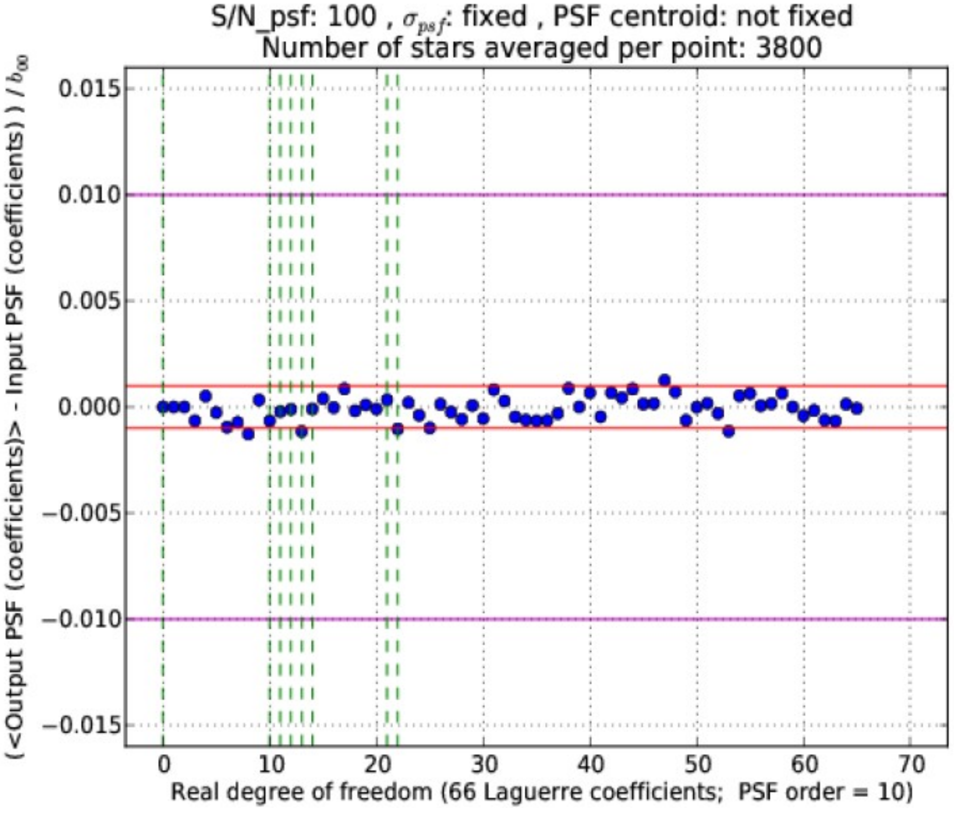
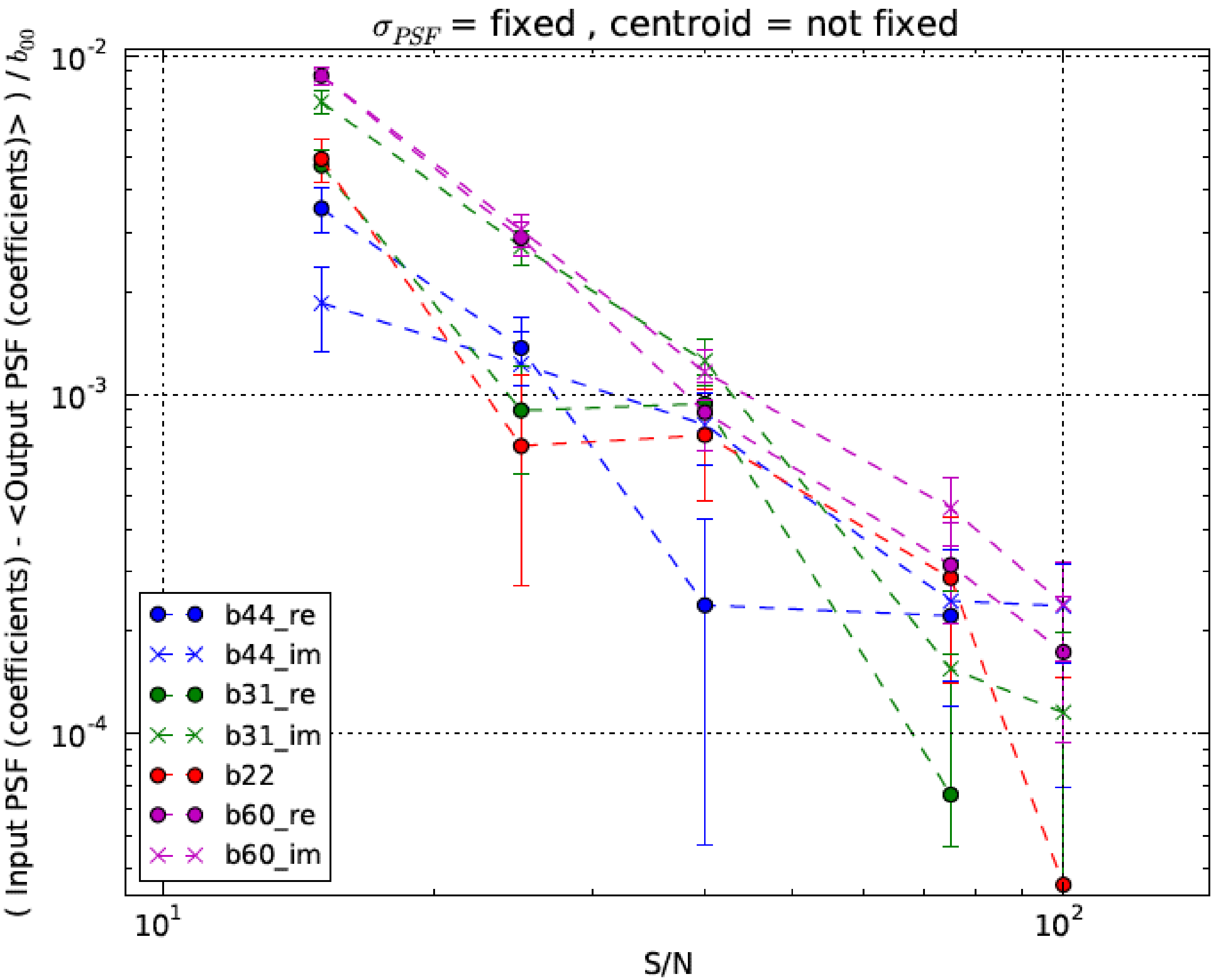
$$I(r,\theta) = \sum_{p,q\geq 0} b_{pq}\psi^{\sigma}_{pq}(r,\theta)$$





Old tests with measurepsf



Bias scales roughly as (S/N)^(-2), and gets Below 10^-3 (DES requirement) at about S/N=45.

Stars that will be used in DES for PSF measurement are bright, high-S/N stars.

Current tests with PSFEx: Images created with GalSim

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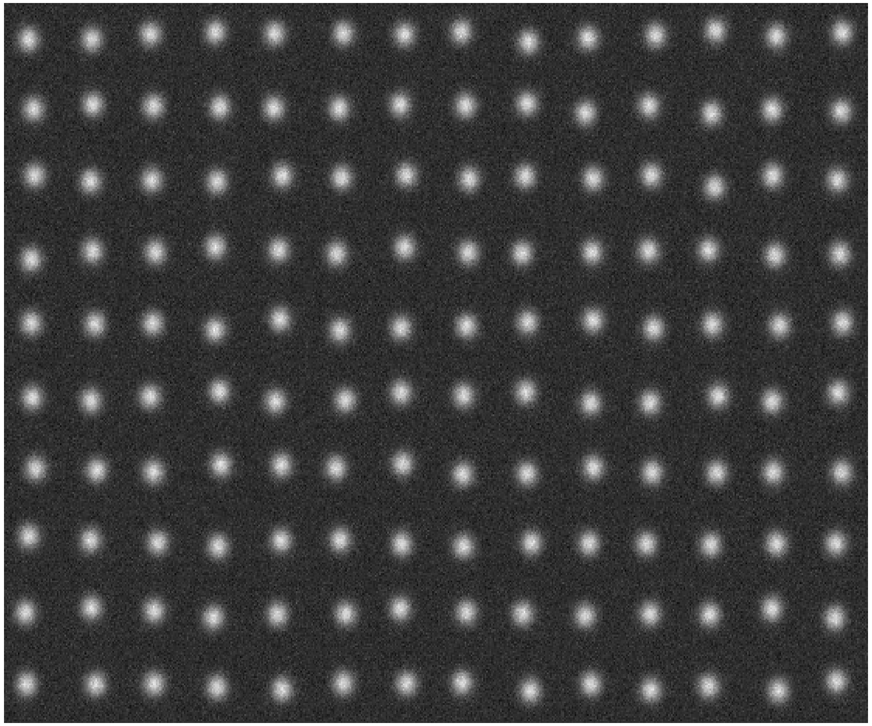
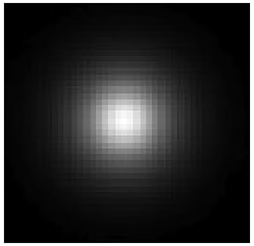
https://github.com/GalSim-developers/GalSim

Sérsic profiles: $$I(r) = I_h \exp\left\{-b_n\left[\left(\frac{r}{r_h}\right)^{1/n} - 1\right]\right\}$$

n=0.5: Gaussian
n=1: Exponential (disk gals.)
n=4: de Vaucouleurs (elliptical gals.)

Moffat PSF, Kolmogorov, Diffraction limited.



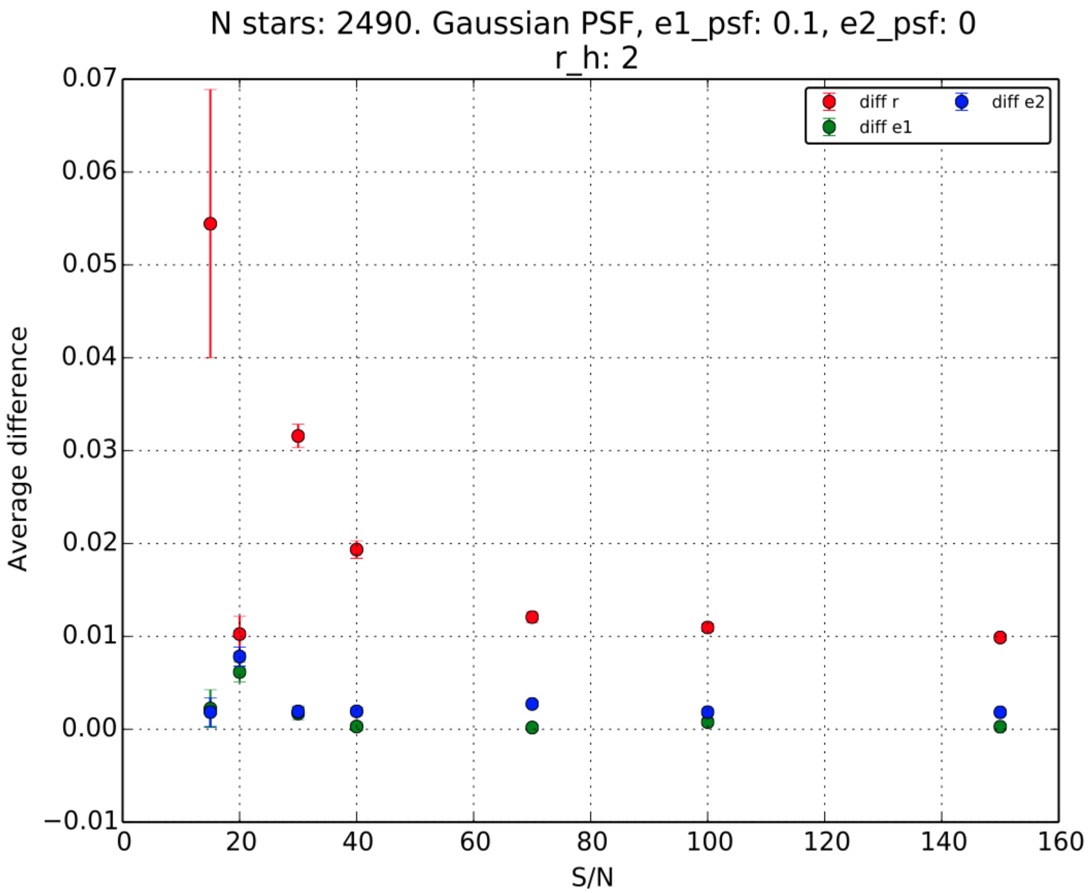


Gaussian PSF

Parameter Space:

- Galaxy Type
- PSF Ellipticity
- Shear (input distortion)
- Significance: S/N
- Galaxy Ellipticity
- PSF Size
- Galaxy Size
- Pixel Size
- PSF type

Current tests with PSFEx



Current tests with PSFEx

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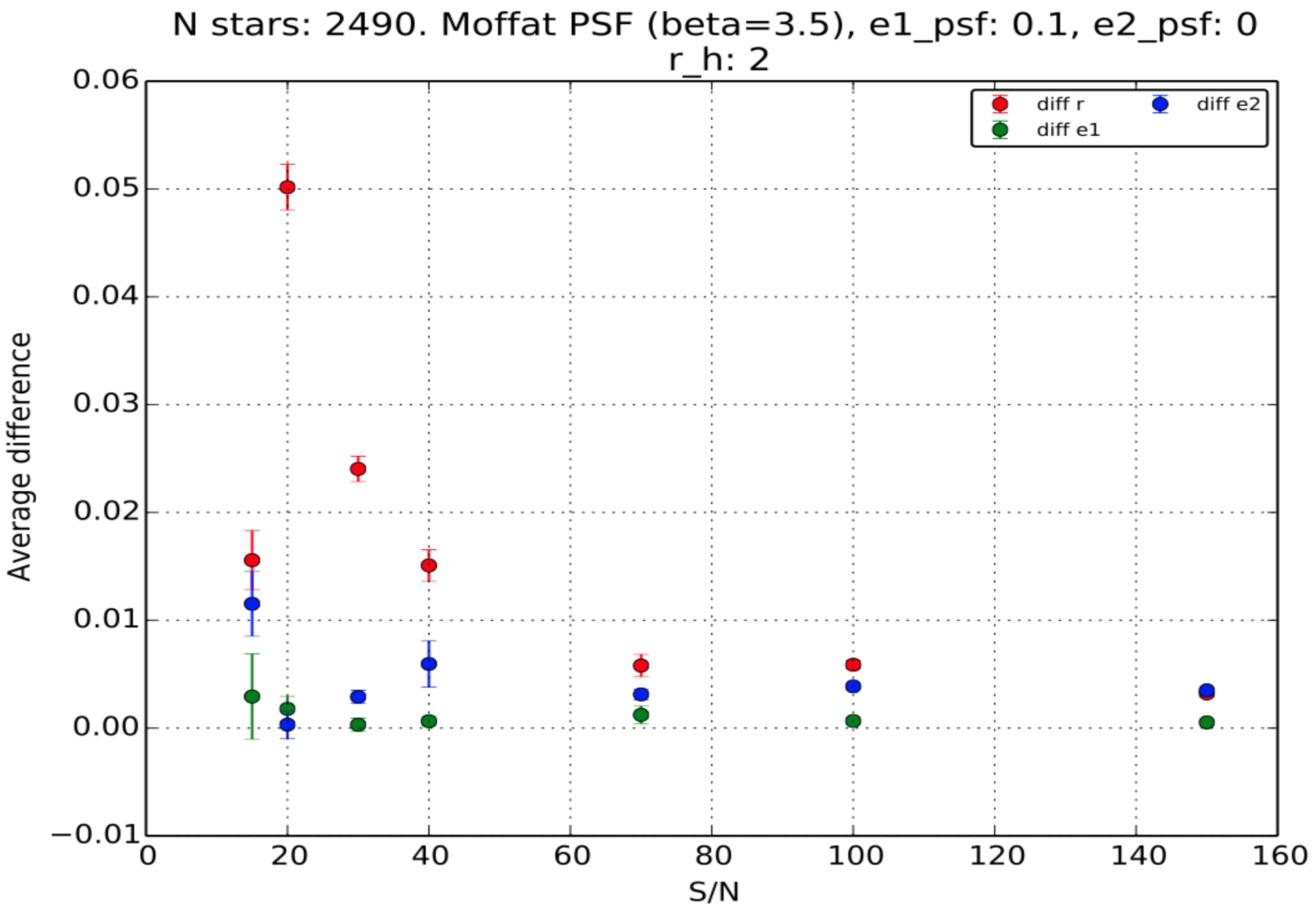

Plans

- Customized tests of PSFEx and measurepsf (shapelets)
- Paper on transverse electric fields in DECam CCDs: first version on ArXiv, but still needs DES revision. Will be submitted to Publications of the Astronomical Society of the Pacific (PASP).

- Stacked cluster lensing in DES. Erin has started to look at surface density contrast with DES first data.

- DES meeting at UIUC next week.

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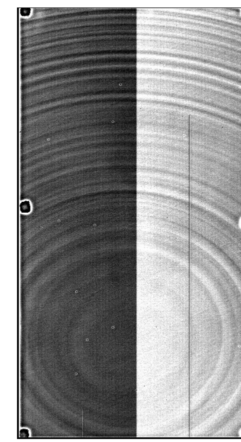
Transverse electric fields effects in DECam devices: tree rings and glowing edges

Andrés Alejandro Plazas Malagón
Department of Physics
Cosmology and Astrophysics Group

BROOKHAVEN NATIONAL LABORATORY



In collaboration with **Gary M. Bernstein** (University of Pennsylvania) and **Erin S. Sheldon** (Brookhaven National Laboratory)

Precision astronomy with fully-depleted CCDs Workshop,
Brookhaven National Laboratory,
November 18th-19th, 2013

Outline

* Structures in dome flats:
  - Tape bumps
  - **Glowing edges**
  - **Tree rings**

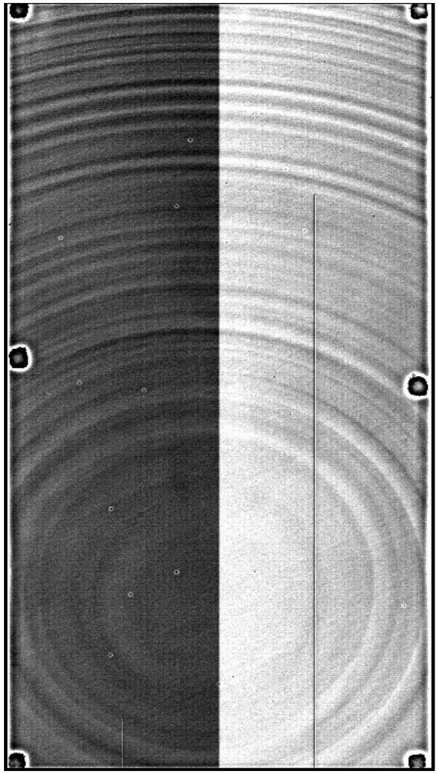
* Redistribution of charge due to transverse/lateral electric fields: pixel area variations.

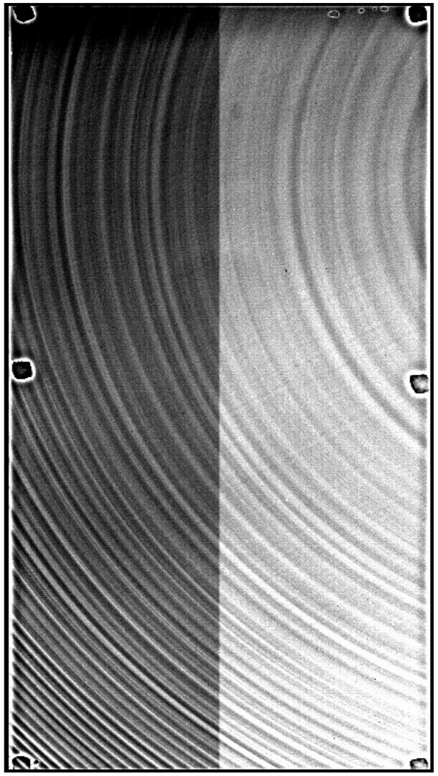
* Impact on astrometric and photometric residuals.

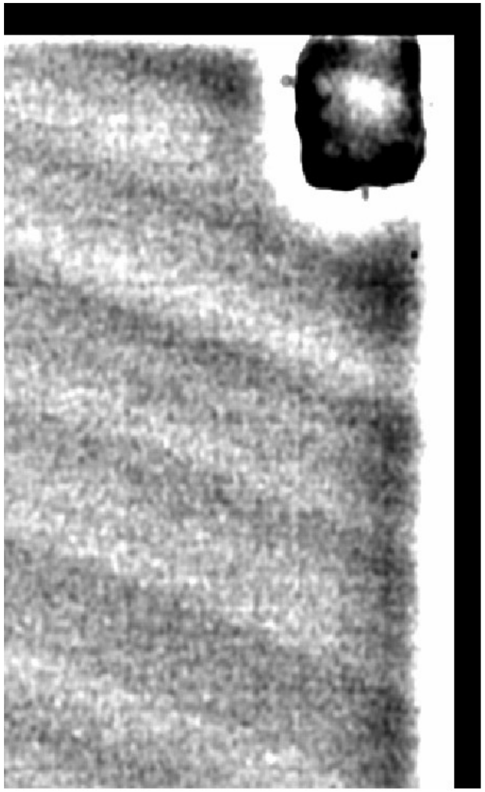
* Photometric and astrometric templates from dome flats, to improve astrometric and photometric solutions.

* Conclusion and summary.

Structures in flats







Glowing Edges and Tape Bumps

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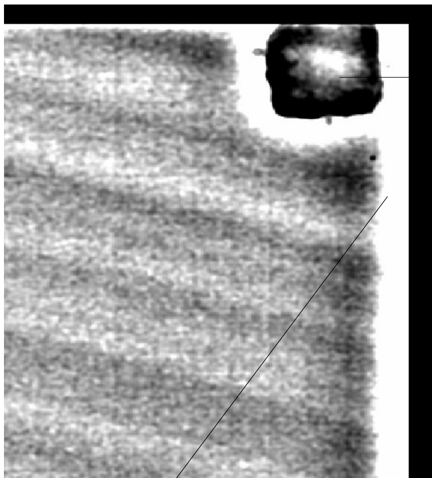
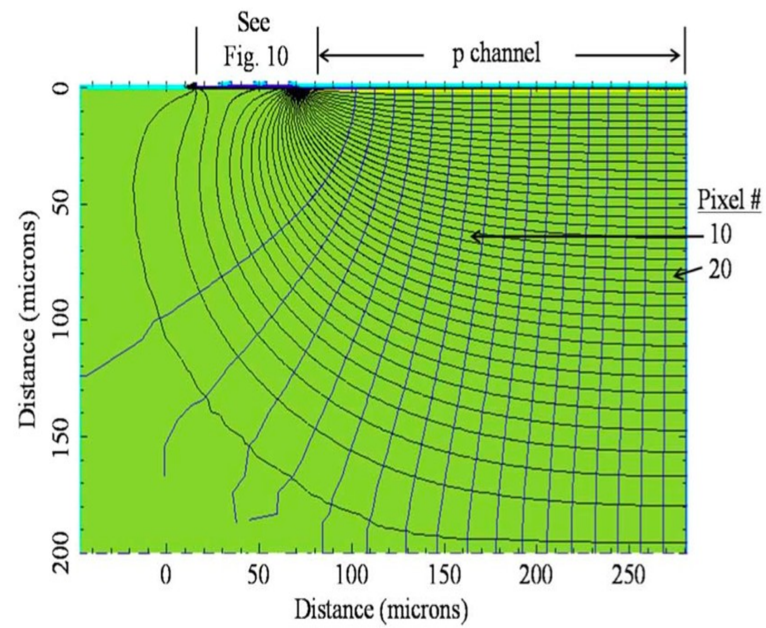


Tape bumps: small gap between CCD and aluminum nitride (AIN) is filled with double-sided tape. Physical deformation that bends electric fields.

Will be masked in DES data.

Glowing edges: electric fields are wider than active pixels at the edges of the CCDs, stretching the effective area of the pixels.

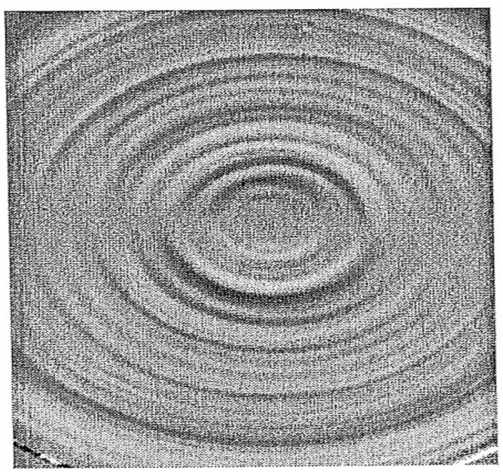


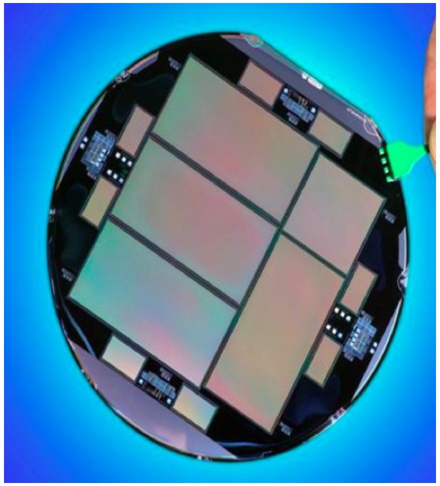
Credit: Holland et al., 2009

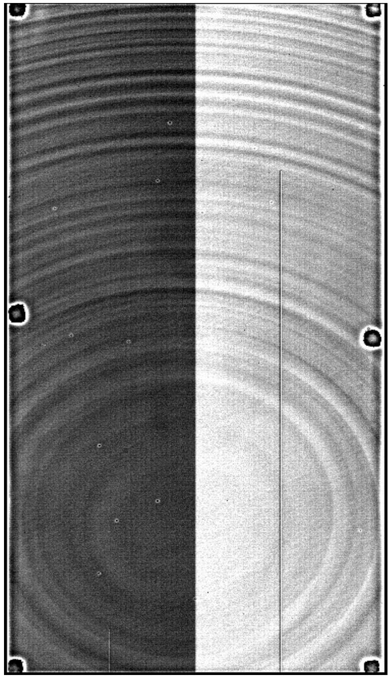
Tree rings

High-resistivity CCDs are fabricated by using the floating zone (FZ) method. In the process, circularly symmetric gradient of resistance (doping) distribution are left behind.

Photoscan of a wafer surface







From Altmannshofer et al. 2003

Pixel area variations

* Transverse fields superpose with existing **E** fields in CCD resulting in distorted electric field lines.

* Redistribution of charge ⟶ **astrometry**

* Effective area of pixel changes ⟶ **photometry**

* Flat fields give a map of variations in pixel uniformity (PRNU), with contributions from changes in sensitivity(QE) **and** pixel area.

Impacts on astrometry and photometry

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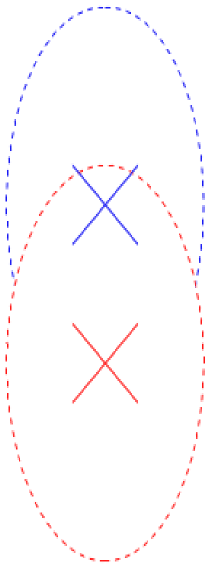
* **Astrometric solution:** map from pixel to sky coordinates.
Used when stacking images to detect objects (DES requirement: match of < 15 mas between different exposures)



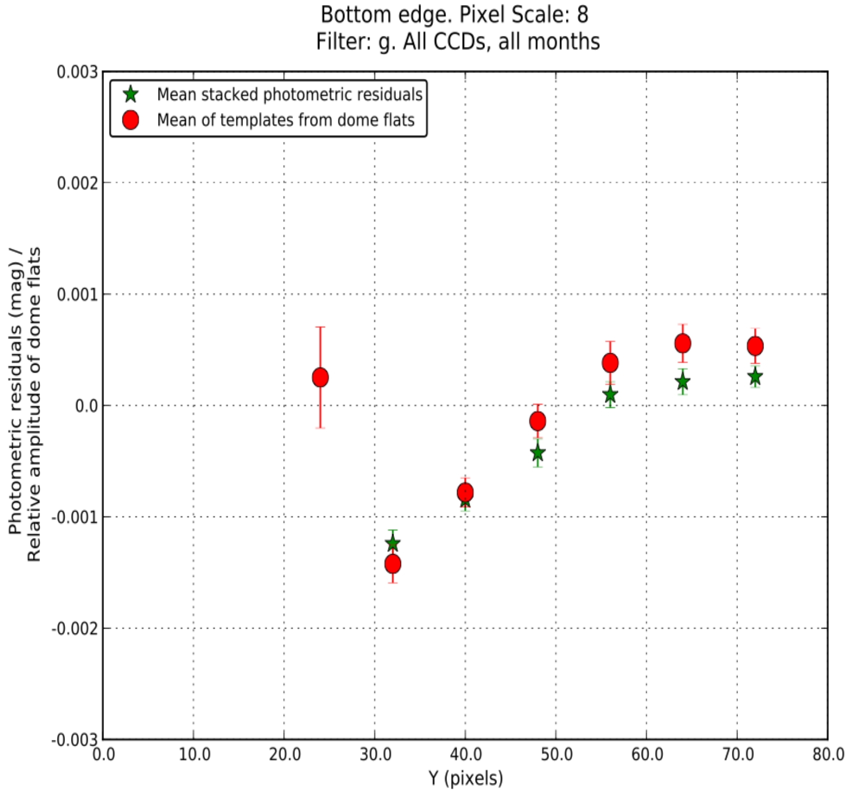
* **Photometric solution:** solution for star flat and zeropoint calibrations for individual exposures simultaneously.
DES requires 2% photometry.

* If glowing edges and tree rings are not included in the optimizations, patterns will remain.

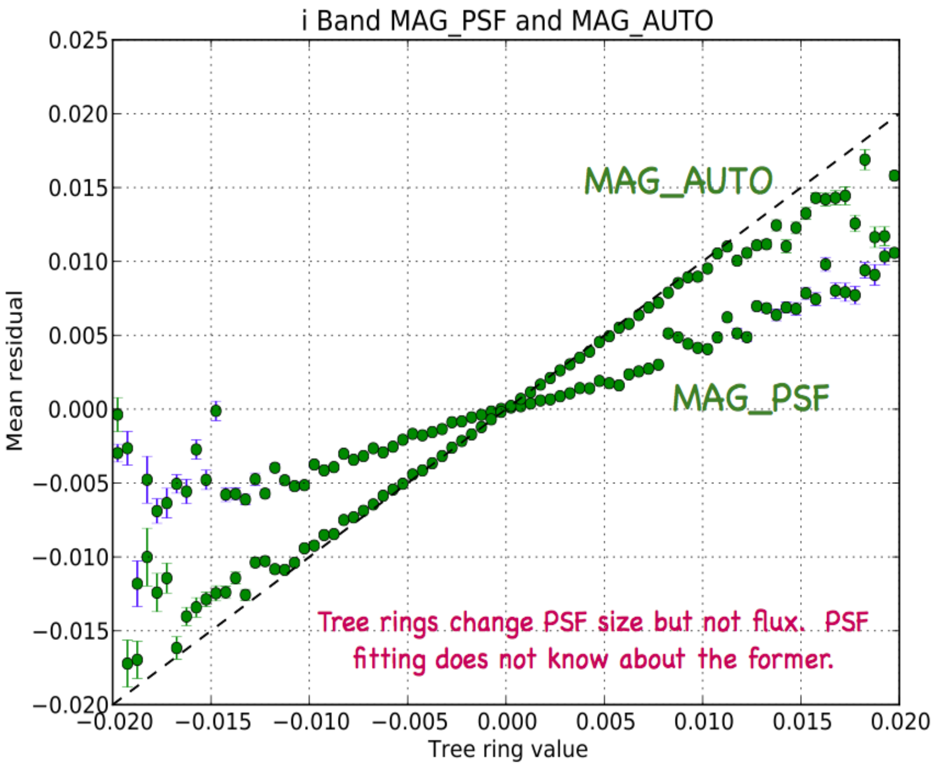
See Gary Bernstein's talk in this workshop for more details about these functions and star flats for DECam data.

Impacts on photometry

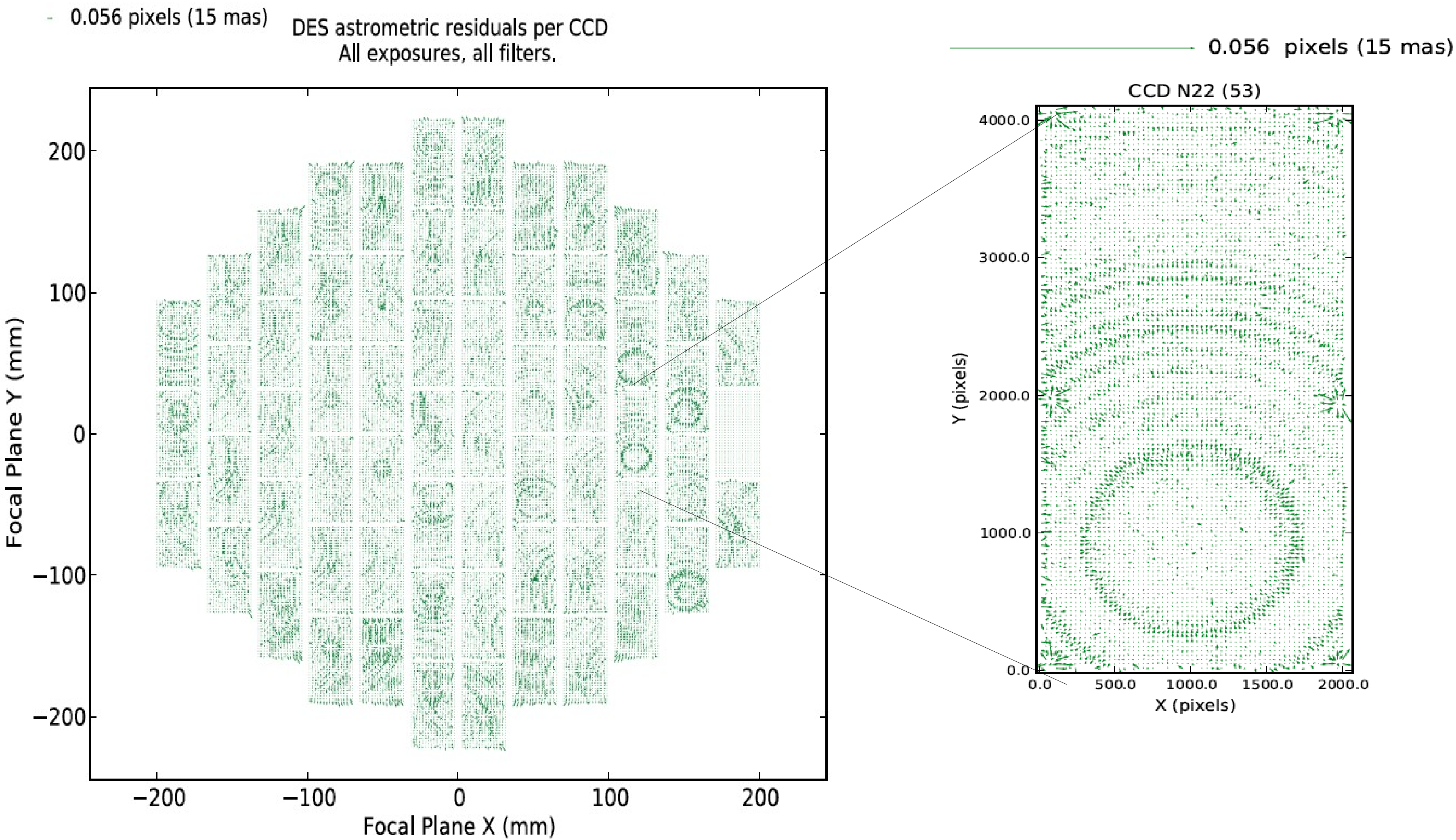
Glowing edge



Tree rings:



Impacts on astrometry



Templates from flats

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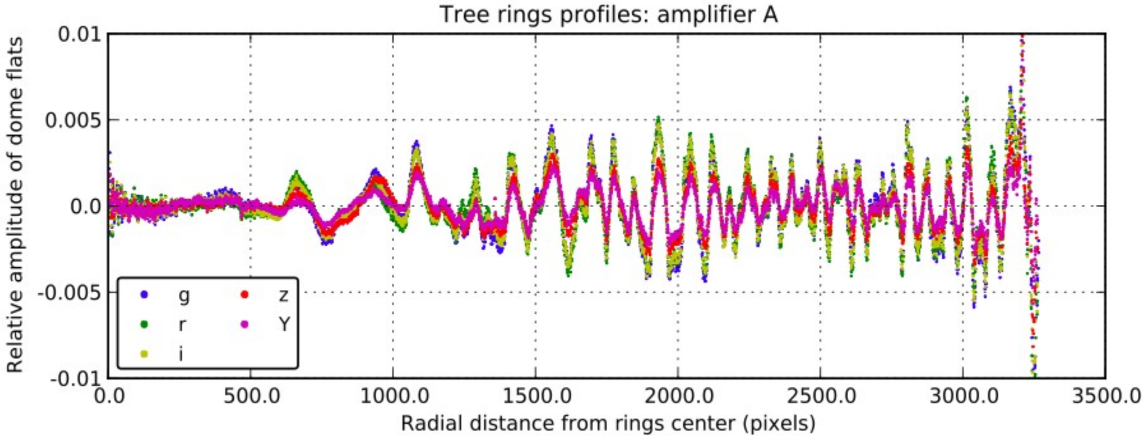
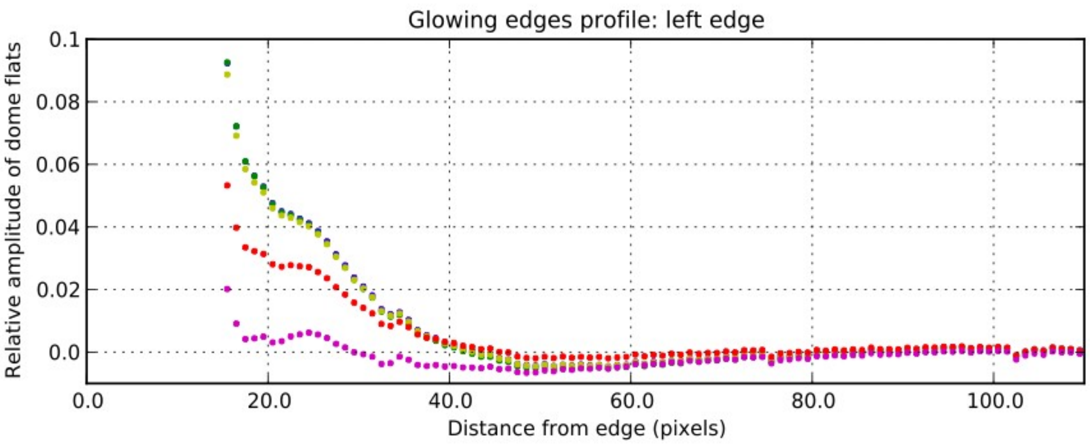
* Use dome flats to measure the relative amplitude of the tree rings and glowing edges as a function of CCD position. Incorporate templates in astrometric and photometric solutions.

CCD: N22 (53)



ratio	A amplifier	B amplifier
r-band/g-band	0.991 ± 0.00229	0.983 ± 0.00633
i-band/g-band	0.9512 ± 0.00248	0.9435 ± 0.00639
z-band/g-band	0.5793 ± 0.00627	0.5757 ± 0.00605
Y-band/g-band	0.4260 ± 0.00719	0.4279 ± 0.00751



* Amplitude is larger for shorter wavelengths.

* On average, photons with short wavelength are absorbed closer to the back window.

Wavelength dependence: a model

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ratio	A amplifier	B amplifier
r-band/g-band	0.991 ± 0.00229	0.983 ± 0.00633
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z-band/g-band	0.5793 ± 0.00627	0.5757 ± 0.00605
Y-band/g-band	0.4260 ± 0.00719	0.4279 ± 0.00751

Can we calculate the expected relative amplitude of the tree rings and glowing edges as a function of wavelength?

$$I_{\rm F} = \frac{\int_{\lambda_{\min}}^{\lambda_{\max}} d\lambda \int_0^d dy\ \lambda F(\lambda) S_\lambda(\lambda) f(y,\lambda)\ \partial_y \Delta X_\perp(y)}{\int_{\lambda_{\min}}^{\lambda_{\max}} d\lambda \int_0^d dy\ \lambda F(\lambda) S_\lambda(\lambda) f(y,\lambda)}$$

- We need:

* SED of source: LEDs that illuminated dome flats
* Transmission response of instrument per broad band
* PDF of a photon being absorbed in [y, y+dy] interval: depends on silicon absorption coefficient
* Lateral displacement of charge packet: depends on transverse and parallel fields →

$$\Delta X_\perp = \int_0^y dy' \frac{E_\perp(y')}{E_{||}(y')}$$

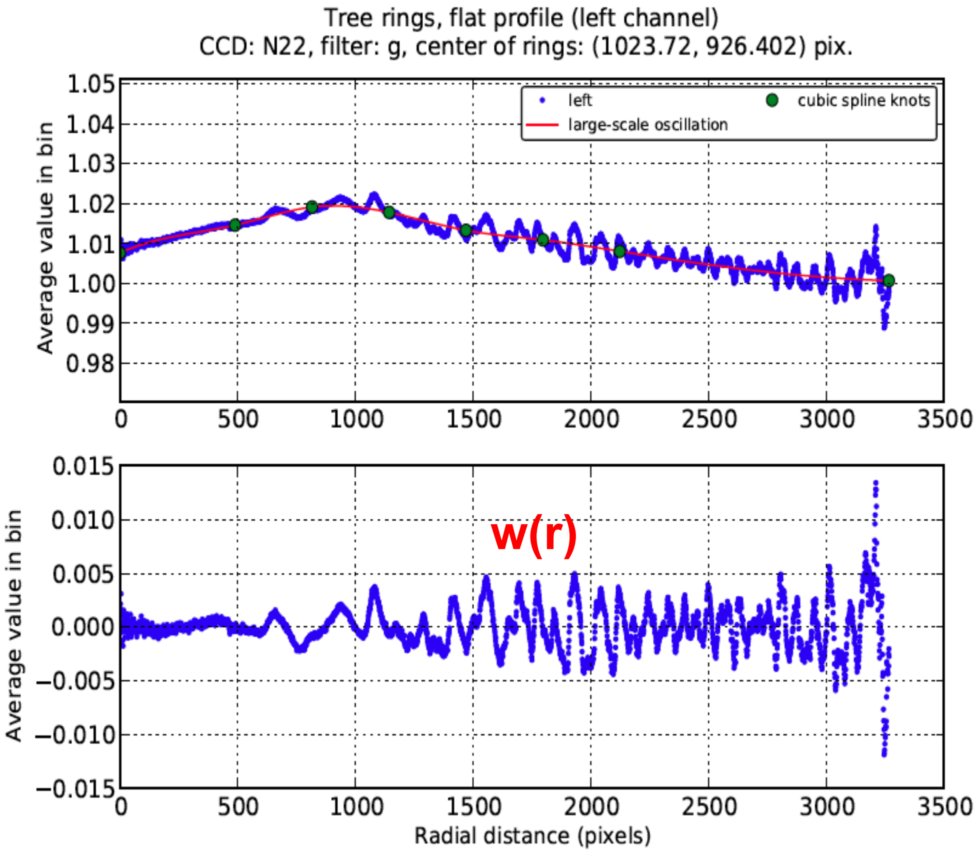
$$E_{||}(y) \propto y/d$$

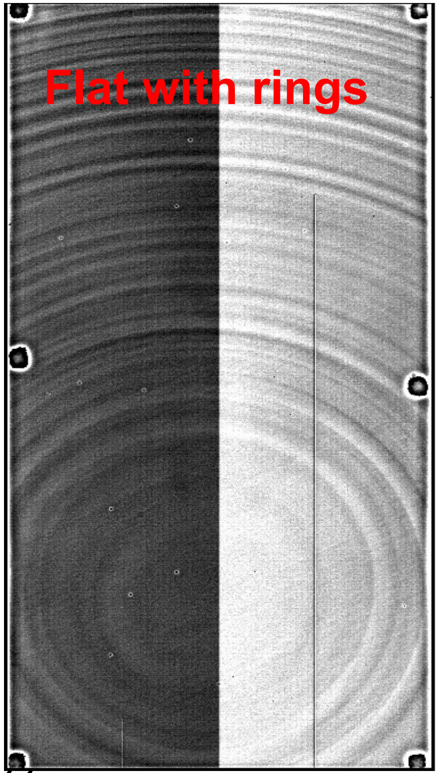
$$E_\perp(y) \propto y(1 - y/d)$$

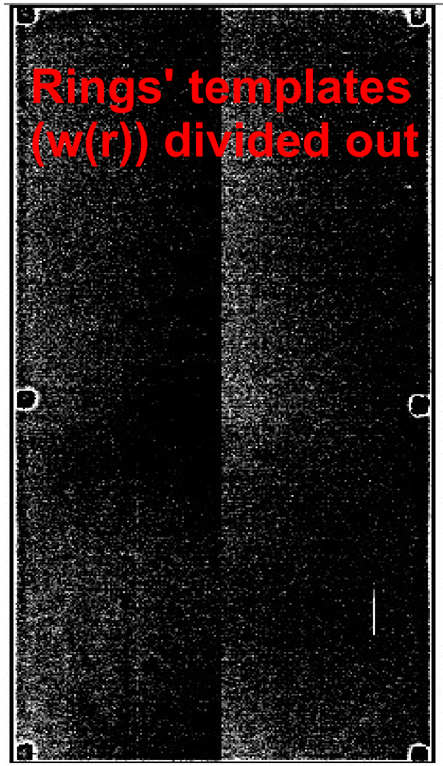
Tree rings: radial profiles

* Assuming that rings are **concentric**, identify their **center** in a given CCD dome flat.

* Bin the counts radially, as a function distance with respect to distance from the center. This gives us the radial profile of the tree rings (a function **w(r)**).







Tree rings: astrometric templates

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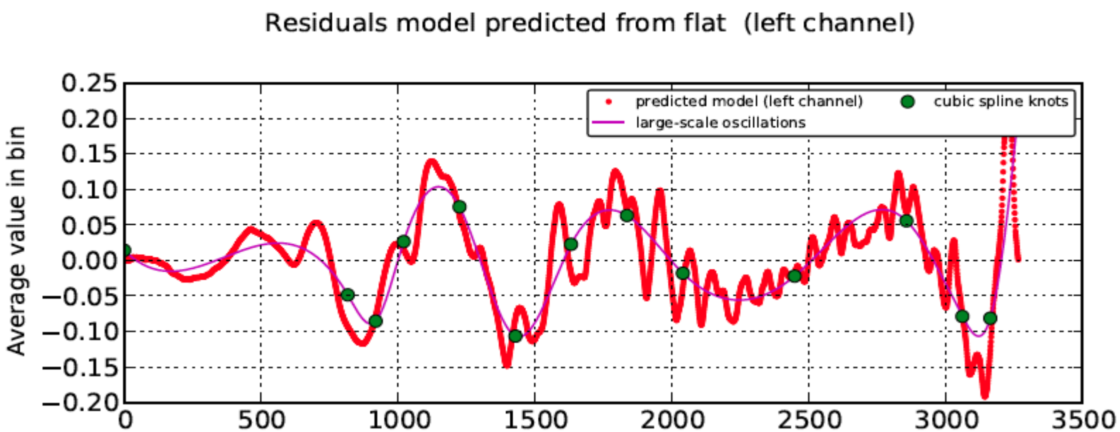
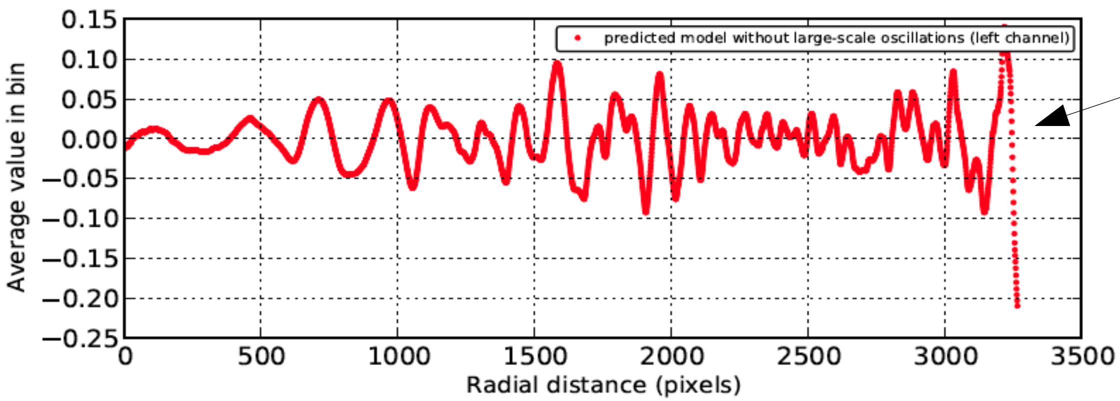
* A photon that hits the CCD at a position **r** is seen as a position **r' = r + f(r)**. **f(r)** is the astrometric distortion.

* From the **dome flats**, we can measure **w(r)** and predict the distortion in astrometry (the **f(r)** perturbation).





* If the illumination surface brightness is nearly constant, then the number of photons per pixel (w(r)) in a flat is proportional to the solid angle of the sky that the pixel sees.

* The solid angle subtended by a pixel on the sky is related to the Jacobian of the astrometric distortion map: **1+ w(r) = |det J|**

Rings:

$$f(r) = -\frac{1}{r}\int r w(r) dr$$

Edges:

$$f(x) = -\int w(x) dx$$

Tree rings: relation to astrometry

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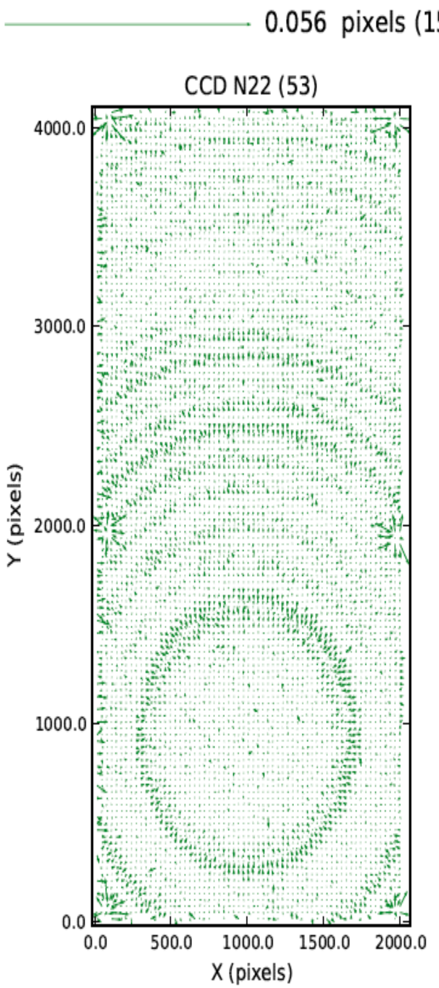
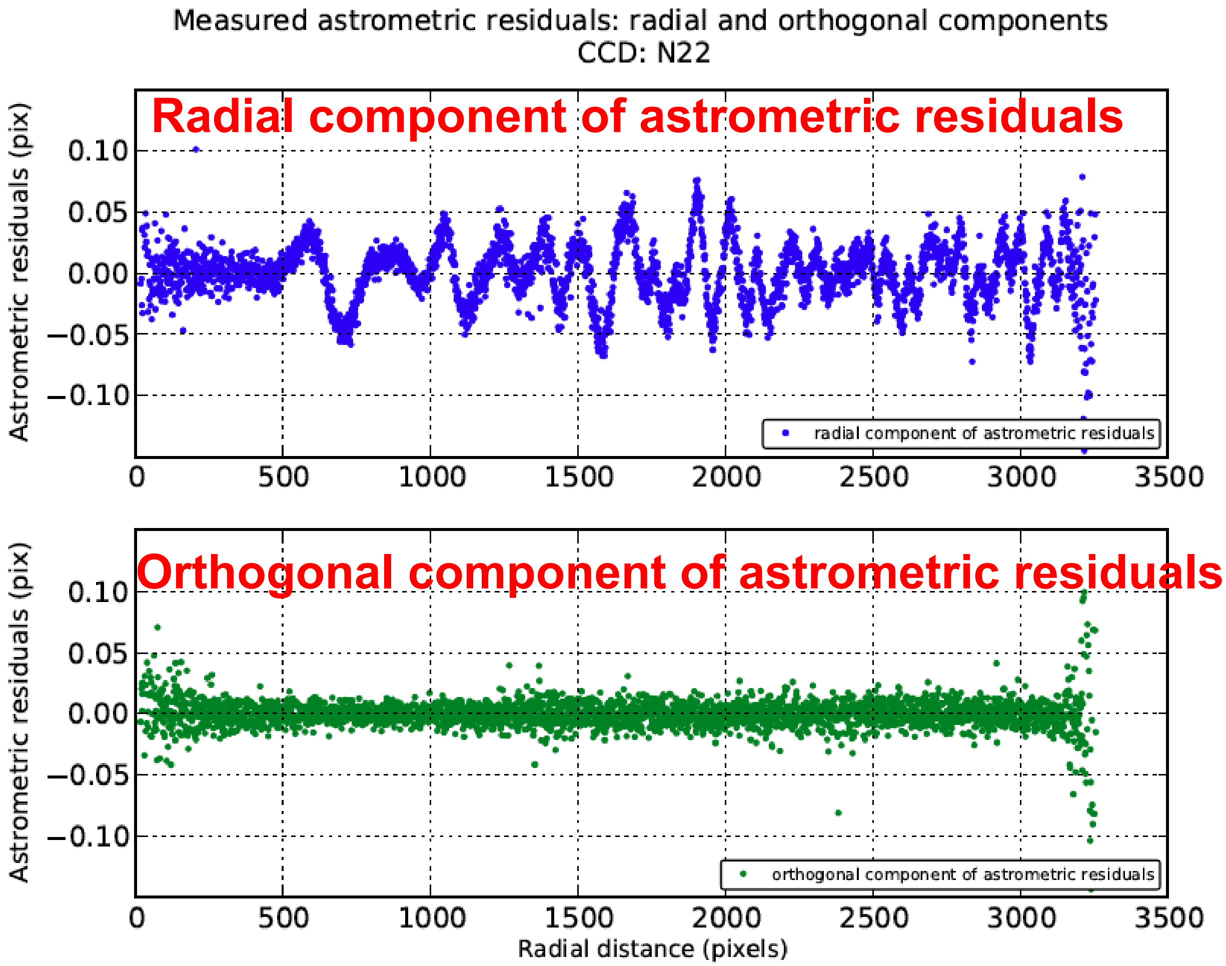
* From the star flats, we can measure the astrometric signature:





Tree rings: relation to astrometry

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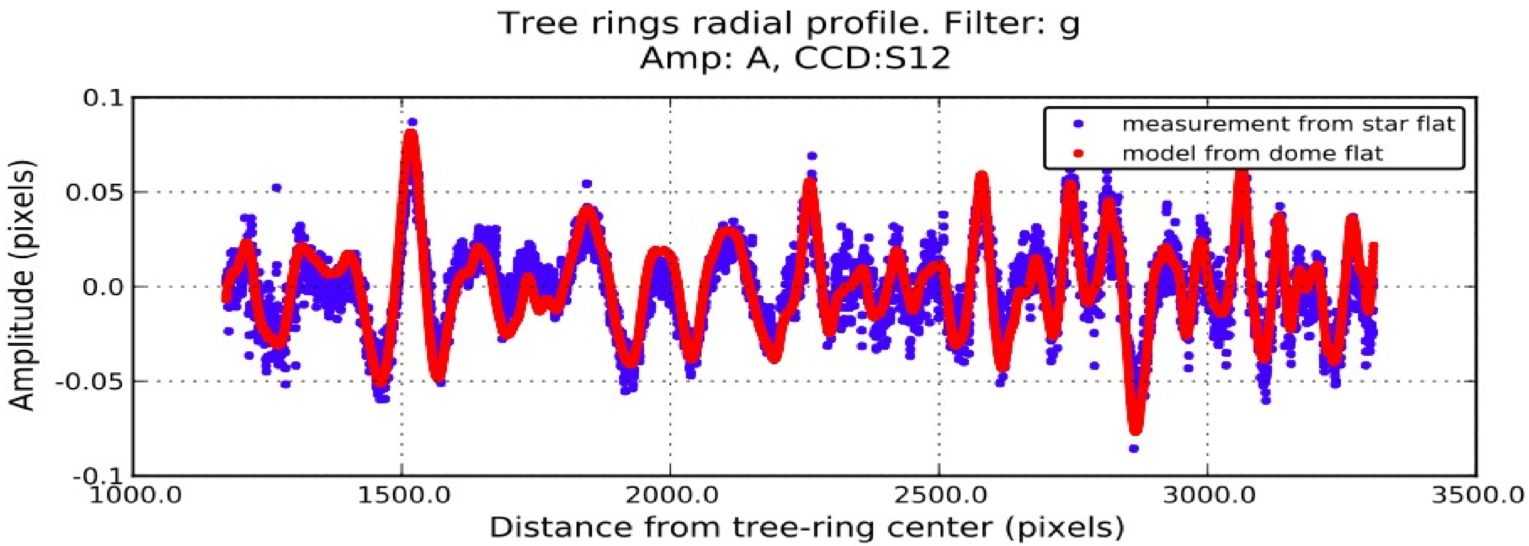
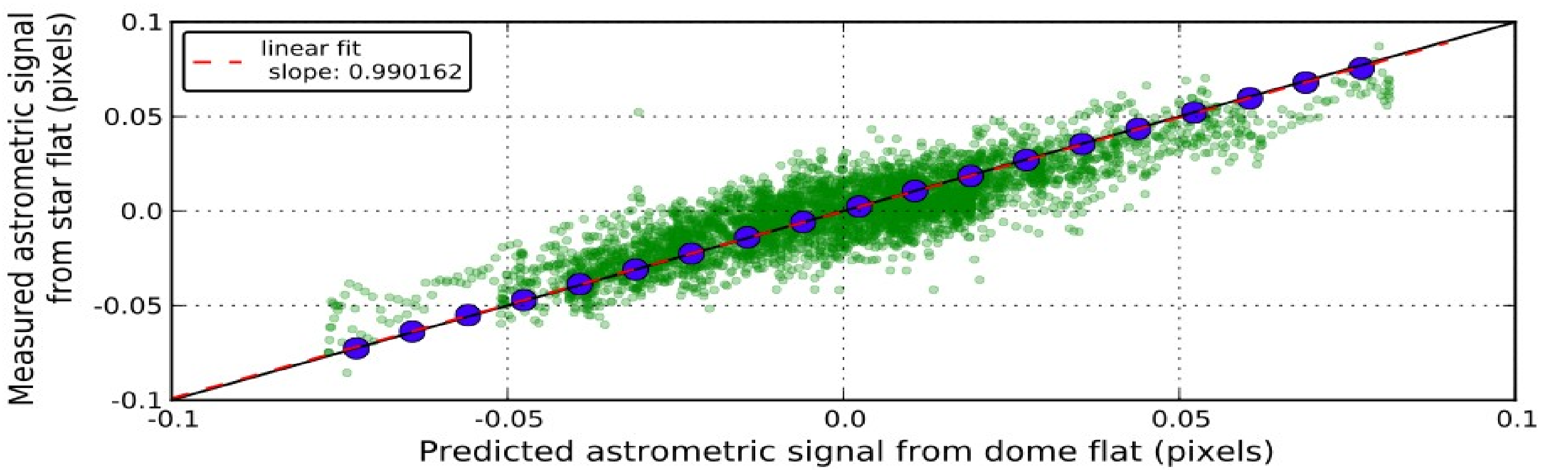
...and then we can compare the prediction to the measurements:





Summary and conclusions

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* Spurious transverse electric fields in CCD redistribute charge between neighboring pixels, modifying the effective pixel area.

* Structures are visible in dome flats: tape bumps, tree rings, glowing edges. They are not due to QE variations.

* Photometric and astrometric measurements are impacted by these structures.

* Templates of the amplitude of this effect as a function of position can be constructed from dome flats to improve on the calculation of the astrometric and photometric solutions.

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Thanks!

-Thanks to:

Ivan Kotov	Morgan May	Darren DePoy
Steve Holland	Tom Dielh	Ting Li
DES WL working group	Andrei Nomerotski	W. Wester

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Extra Slides

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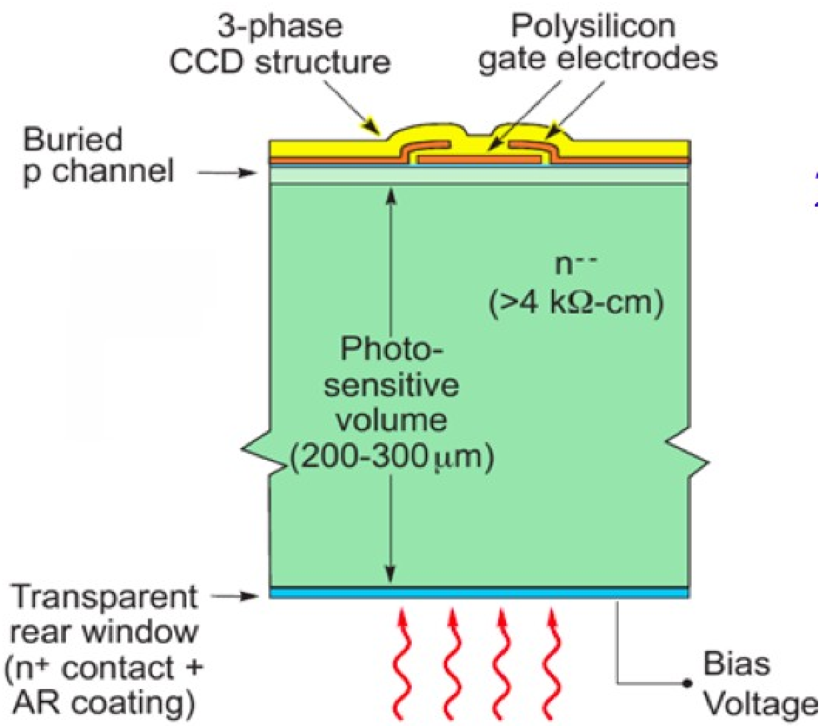

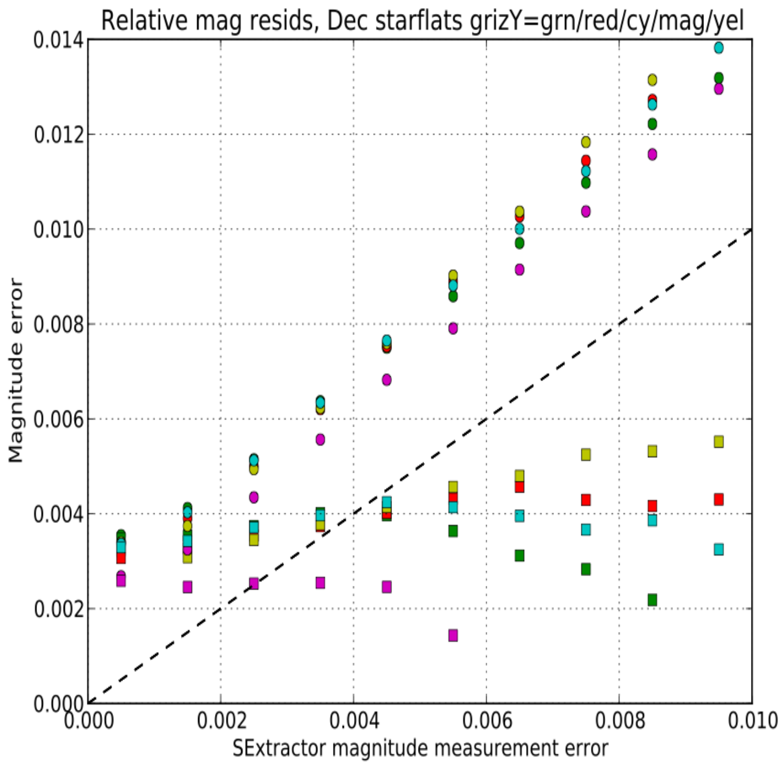

$$\frac{dF}{dy} = f(y) = \frac{\alpha \exp(-y\alpha)}{1 - \exp(-2d\alpha)}$$

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